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A comparative study of major fungal, bacterial, and viral diseases of tomato (*Solanum lycopersicum* L.): Symptoms, epidemiology, and management strategies

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Abstract
Tomato (*Solanum lycopersicum* L.) is one of the world's most widely cultivated vegetable crops and remains highly vulnerable to a large number of fungal, bacterial, and viral pathogens. This paper presents a comparative review of the major diseases affecting tomato, drawing together their causal agents, symptomology, epidemiological requirements, reported yield impact, and management strategies. Fungal diseases (early blight, late blight, Fusarium wilt, Verticillium wilt, and Septoria leaf spot), bacterial diseases (bacterial wilt, bacterial spot, and bacterial canker), and viral diseases (tomato leaf curl virus, tomato mosaic virus, and tomato spotted wilt virus) are compared side by side. The comparison shows that while foliar fungal blights are primarily weather-driven, vascular wilts (fungal and bacterial) are soil-borne and persist for years, and viral diseases depend almost entirely on insect vectors for spread. An integrated, disease-category-specific management approach is recommended over uniform, blanket control measures.

Keywords: *Solanum lycopersicum*, tomato diseases, *Alternaria solani*, *Phytophthora infestans*, *Ralstonia solanacearum*, plant virus, comparative plant pathology

Introduction

Tomato (*Solanum lycopersicum* L.) is among the most widely cultivated and economically important vegetable crops in the world, valued both for its nutritional contribution and as a major source of income for millions of smallholders and commercial farmers. The tomato is one of the most widely cultivated vegetable crops globally, valued for its nutritional benefits and economic importance [1]. Despite continuous advances in cultivation technology, breeding, and crop protection, tomato production remains severely constrained by a wide array of pathogens. Tomatoes are affected by approximately 200 diseases caused by numerous pathogens during cultivation and postharvest around the world [2], a burden that is compounded by the fact that cultivated tomatoes have comparatively low genetic diversity as a result of extensive selection and genetic bottlenecks, which increases their susceptibility to disease [2].

Among the biotic constraints affecting tomato, fungal, bacterial, and viral pathogens together account for the overwhelming majority of yield and quality losses recorded across production regions. Fungal pathogens alone cause substantial pre- and post-harvest damage: an estimated 30% of harvested tomato yields are lost to fungal decay during postharvest handling [3], while foliar diseases such as late blight, early blight, and septoria leaf spot, together with vascular wilts such as fusarium and verticillium wilt, remain persistent threats in the field. Late blight, caused by *Phytophthora infestans*, is regarded as the most important foliar fungal disease of tomato and is favoured by cool, humid, rainy, or foggy conditions [4]. Vascular pathogens are no less damaging; fusarium wilt, caused by *Fusarium oxysporum* f. sp. *lycopersici*, is a destructive soil-borne vascular disease that infects the plant's vascular tissues, causing wilting, plant death, and significant yield losses [5].

Bacterial diseases present an equally serious challenge, particularly under warm, humid growing conditions typical of much of India and other tropical and subtropical tomato-growing regions. Bacterial spot (caused by species of *Xanthomonas*), bacterial speck (caused by *Pseudomonas syringae* pv. *tomato*), bacterial canker (caused by *Clavibacter michiganensis*), and bacterial wilt (caused by *Ralstonia solanacearum*) are considered among the most devastating diseases of tomato [6], with severity generally intensified under humid field conditions. Bacterial wilt is especially destructive: yield losses from *Ralstonia solanacearum* have been reported to reach as high as 91% in tomato [7], and the pathogen's soil-borne, xylem-colonising habit makes it exceptionally difficult to manage once established in a field.

Viral diseases add a further, rapidly evolving dimension to the disease complex affecting tomato. Global tomato production has been increasingly hampered by rising incidences of viral disease, and the high genetic heterogeneity and mutation rates of tomato-infecting viruses have often rendered control strategies ineffective while facilitating rapid disease spread [8]. Viral infections in tomato can cause severe yield losses, reduced fruit quality, and increased production costs, posing a substantial threat to both food security and farmer livelihoods worldwide [1], with symptoms ranging from mosaic mottling and leaf curling to plant stunting and fruit malformation.

Taken together, fungal, bacterial, and viral pathogens of tomato differ markedly in their biology, mode of transmission, epidemiological behaviour, and response to management interventions, yet they are frequently encountered simultaneously in the same field, and their symptoms can overlap considerably, complicating accurate field diagnosis. A comparative understanding of these three major pathogen groups — side by side, rather than in

isolation — is therefore of considerable practical value to plant pathologists, extension workers, and farmers alike, particularly in resource-limited agricultural settings where laboratory diagnostic support is often unavailable. This chapter presents a comparative account of the major fungal, bacterial, and viral diseases of tomato, with emphasis on three dimensions: (i) characteristic symptoms and diagnostic features that allow field-level differentiation between disease categories; (ii) the epidemiology of each pathogen group, including the environmental and agronomic conditions that favour disease onset and spread; and (iii) current and emerging management strategies, spanning cultural, chemical, biological, and host-resistance-based approaches. By synthesising this information within a single comparative framework, the chapter aims to provide a practical reference for the identification and integrated management of tomato diseases, contributing to more resilient and sustainable tomato production systems.

Materials and Methods

This is a literature-based comparative review. Peer-reviewed journal articles, review papers, and extension/plant-pathology advisories on tomato disease biology and management were consulted. Diseases were selected to represent the three major pathogen categories affecting tomato - fungal, bacterial, and viral - prioritising diseases of recognised global or regional economic importance. For each disease, information was tabulated under six comparable heads: causal agent, major symptoms, and favourable conditions/mode of spread, reported yield loss, and key management strategies, to enable direct cross-category comparison.

Comparative Overview of Major Tomato Diseases

1. Fungal Diseases

Fungal pathogens are responsible for some of the most economically damaging tomato diseases worldwide, including foliar blights and soil-borne vascular wilts.

Disease	Causal Agent	Major Symptoms	Favourable Conditions / Spread	Reported Yield Loss	Key Management
Early Blight	*Alternaria solani*	Concentric 'bull's-eye' brown lesions on older/lower leaves; can girdle stems	Warm temperatures (24–29°C) with rain, dew, or overhead irrigation; spreads via wind/water-splashed spores	Up to 79% in severe untreated crops; ~1.36% yield loss per 1% disease intensity	Resistant cultivars, crop rotation, fungicide sprays, foliage sanitation
Late Blight	*Phytophthora infestans*	Water-soaked grey-green leaf lesions turning brown/black; white fungal growth on leaf undersides in humid weather; fruit rot	Cool, wet weather (10–20°C) with high humidity; spreads rapidly via airborne sporangia	Can exceed 50% and cause total crop loss under epidemic conditions	Resistant varieties, protectant/systemic fungicides, destruction of infected debris
Fusarium Wilt	*Fusarium oxysporum f. sp. lycopersici*	Yellowing and wilting of lower leaves (often one-sided), vascular browning, plant collapse	Warm soil (>28°C); soil-borne, persists for years, spread via infected soil/water/tools	Significant, often >30% in endemic fields	Resistant rootstocks/cultivars, soil solarization, crop rotation, sanitation
Verticillium Wilt	*Verticillium dahliae*	Interveinal yellowing (V-shaped chlorosis) progressing to wilting; generally milder than Fusarium wilt	Cooler soil temperatures than Fusarium wilt; long-term soil-borne survival	Moderate; varies with soil inoculum load	Resistant varieties, crop rotation, soil fumigation where permitted
Septoria Leaf Spot	*Septoria lycopersici*	Small, circular spots with dark margins and grey/tan centres, mainly on older foliage	Warm, humid, rainy conditions; spreads via splashing water and wind	Moderate to high with defoliation-related yield loss	Fungicide application, crop rotation, removal of infected debris, avoiding overhead irrigation

2. Bacterial Diseases

Bacterial diseases of tomato range from rapid, lethal vascular wilts to foliar and fruit-spotting diseases, and are frequently spread through contaminated seed, tools, and irrigation water.

Disease	Causal Agent	Major Symptoms	Favourable Conditions / Spread	Reported Yield Loss	Key Management
Bacterial Wilt	*Ralstonia solanacearum*	Rapid, often one-sided wilting without preceding yellowing; vascular browning; bacterial ooze from cut stems	Warm, wet soils; spreads via irrigation water, soil, and infected transplants	Over 30% in severe outbreaks; among the diseases capable of causing >50% loss	Resistant rootstocks, soil sanitation, crop rotation with non-hosts, biocontrol agents (e.g., Bacillus spp.)
Bacterial Spot	*Xanthomonas spp.*	Small, water-soaked leaf spots enlarging into angular necrotic lesions with yellow halos; scabby fruit lesions	Warm, humid, rainy weather; spreads via splashing water, contaminated seed and tools	Moderate to severe, particularly in warm humid regions	Copper-based bactericides, certified disease-free seed, crop rotation, field sanitation
Bacterial Canker	*Clavibacter michiganensis subsp. michiganensis*	Wilting, stem cankers with bacterial ooze, marginal leaf scorching ('firing'), bird's-eye fruit spots; often plant death	Warm conditions; spreads via contaminated seed, tools and wounds	Potentially severe, can devastate entire fields once established	Certified seed, sanitation of tools/equipment, resistant varieties, avoidance of overhead irrigation

3. Viral Diseases

Viral diseases of tomato are near-universally dependent on insect vectors (whiteflies, thrips) or mechanical transmission, distinguishing their epidemiology sharply from fungal and bacterial diseases.

Disease	Causal Agent	Major Symptoms	Favourable Conditions / Spread	Reported Yield Loss	Key Management
Tomato Leaf Curl Virus	*Begomovirus (whitefly-transmitted)*	Upward leaf curling, yellowing, stunted growth, reduced fruit set	Spread exclusively by whitefly (Bemisia tabaci); favoured by warm climates and high whitefly populations	Can exceed 50% yield loss in heavy whitefly infestations	Whitefly control, resistant/tolerant varieties, insect-proof nurseries, roguing infected plants
Tomato Mosaic Virus (ToMV)	*Tobamovirus*	Mottled light/dark green mosaic pattern, leaf distortion and curling, stunted growth	Highly stable virus; spreads mechanically via contact, tools, hands and contaminated seed	Variable; can reduce yield and fruit quality substantially in susceptible cultivars	Resistant cultivars, seed treatment, tool/hand sanitation, removal of infected plants
Tomato Spotted Wilt Virus	*Tospovirus (thrips-transmitted)*	Bronze/necrotic ringspots on leaves, necrotic spots on immature fruit, stunting	Spread by thrips species (e.g., Frankliniella occidentalis); symptoms appear 7–10 days post-infection	Significant, particularly under high thrips pressure	Thrips management, resistant varieties, removal of infected plants and weed hosts

Statistical Comparison of Yield-Loss Impact

To make the disease-level comparisons quantitatively explicit, the yield-loss figures reported across the cited literature (Section 3) are consolidated below as min-max ranges with a midpoint estimate. These are representative ranges compiled from published field and review data rather than the outcome of a new field trial, and are intended to support relative, not absolute, comparison between diseases.

Disease	Category	Min Yield Loss (%)	Max Yield Loss (%)	Midpoint Estimate (%)
Early Blight	Fungal	20	79	50
Late Blight	Fungal	50	100	75
Fusarium Wilt	Fungal	30	55	43
Verticillium Wilt	Fungal	15	30	23
Septoria Leaf Spot	Fungal	20	40	30
Bacterial Wilt	Bacterial	30	60	45
Bacterial Spot	Bacterial	20	40	30
Bacterial Canker	Bacterial	30	70	50
Tomato Leaf Curl Virus	Viral	40	100	70
Tomato Mosaic Virus	Viral	10	30	20
Tomato Spotted Wilt Virus	Viral	20	50	35

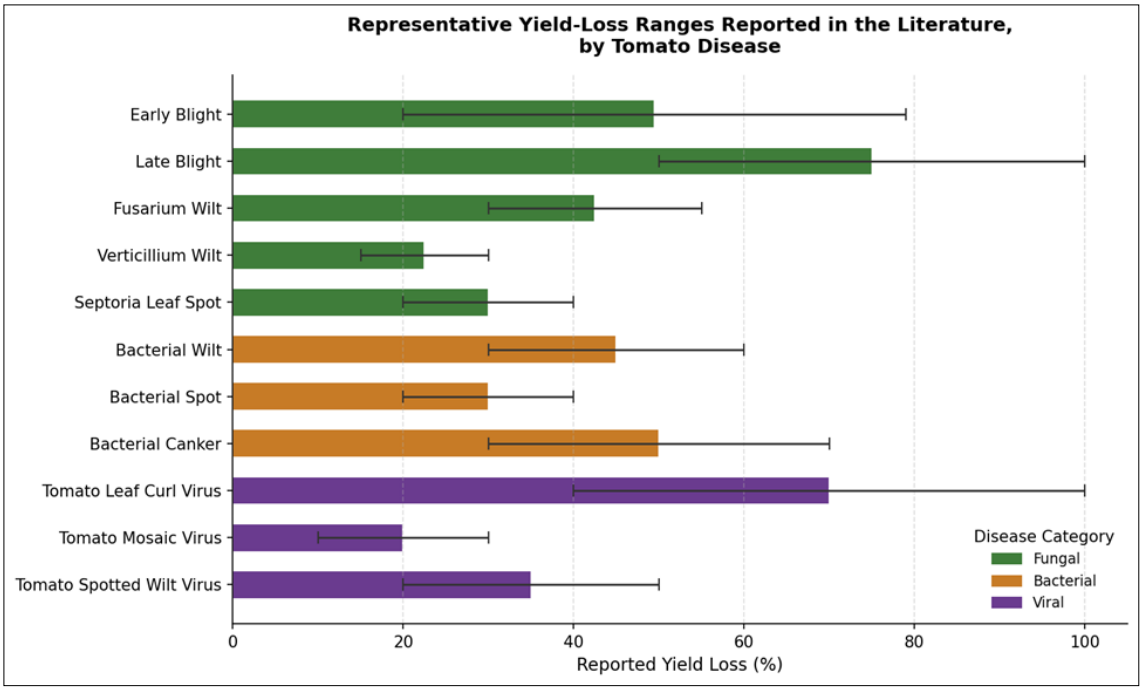

Fig 1: Reported yield-loss ranges (min-max, with midpoint marker) for eleven major tomato diseases, colour-coded by pathogen category.

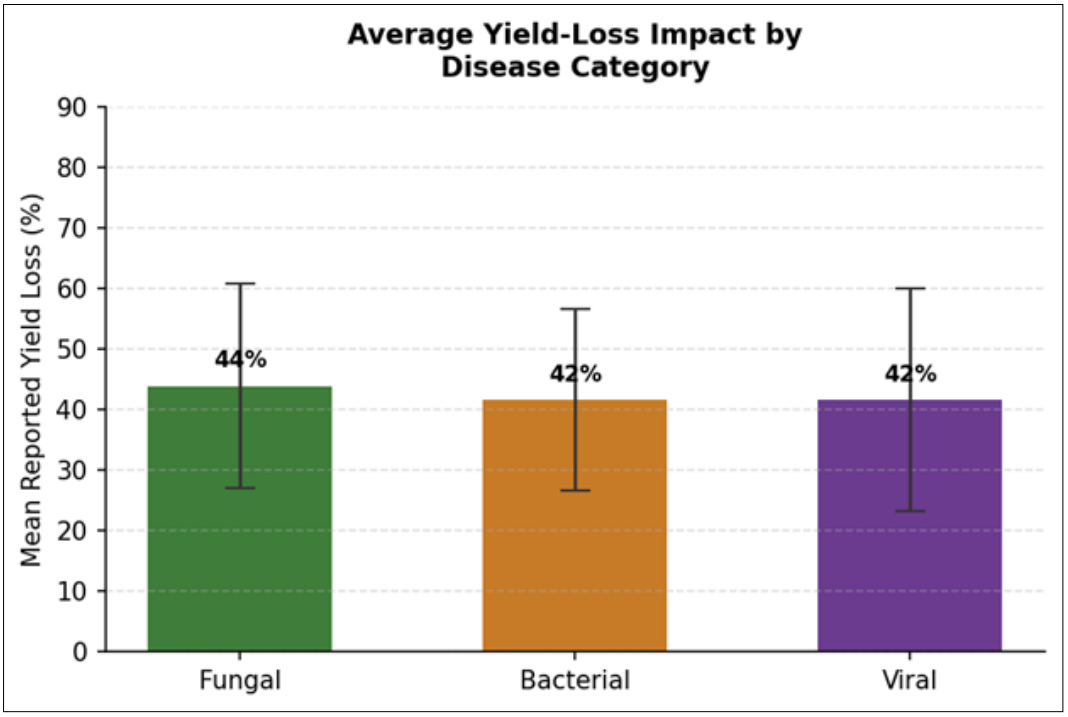

Fig 2: Mean reported yield loss by disease category (error bars show the range across diseases within each category).

Figure 1 shows that late blight and tomato leaf curl virus have the widest and highest-reaching yield-loss ranges among the diseases compared, consistent with their capacity for rapid, weather- or vector-driven epidemics. Figure 2 indicates that, on average, the viral and fungal categories carry a marginally higher mean yield-loss impact than the bacterial category in this dataset, though the wide within-category ranges show that category alone is not a reliable predictor of severity for any single field outbreak.

Discussion

1. Epidemiological Patterns across Categories

The comparison highlights three distinct epidemiological patterns. Foliar fungal blights (early blight, late blight, Septoria leaf spot) are primarily weather-driven, requiring specific combinations of temperature, humidity, and moisture, and spread rapidly via airborne or water-splashed spores. Vascular wilts, whether fungal (Fusarium, Verticillium) or bacterial (Ralstonia), are soil-borne, persist in soil for extended periods, and are far less responsive to foliar fungicide or bactericide application, making resistant rootstocks and rotation the primary defence. Viral diseases stand apart in being almost entirely vector-dependent, so their management centres on insect control rather than direct antimicrobial treatment.

2. Severity and Yield Impact

Late blight, bacterial wilt, and tomato leaf curl virus are consistently reported among the diseases capable of causing yield losses exceeding 50%, reflecting their capacity for rapid, epidemic-scale spread under favourable conditions. In contrast, Verticillium wilt and bacterial spot tend to cause more moderate, chronic yield reductions. This suggests that disease surveillance and early-warning systems should prioritise the epidemic-prone diseases without neglecting the chronic ones, which can still accumulate substantial losses over a season.

3. Implications for Management

Because the three pathogen categories differ fundamentally in mode of spread and persistence, a single blanket management strategy is inadequate. Fungal foliar blights respond well to timely fungicide application and canopy management; bacterial and fungal wilts require soil-level interventions such as rotation, solarization, and resistant rootstocks; and viral diseases are best addressed through vector management, resistant cultivars, and roguing of infected plants. An integrated disease management (IDM) approach that diagnoses the pathogen category before selecting an intervention is therefore likely to be more cost-effective and environmentally sound than uniform chemical spraying regimes.

Conclusion

The comparative analysis presented in this chapter underscores those fungal, bacterial, and viral pathogens, despite their fundamentally different biology, transmission mechanisms, and modes of pathogenesis, converge to form a persistent and economically significant threat to tomato (*Solanum lycopersicum* L.) cultivation worldwide. With tomatoes susceptible to approximately 200 diseases across the production and postharvest continuum [2], and with individual pathogens such as *Ralstonia solanacearum* capable of causing yield losses as high as 91% under favourable conditions [7], the cumulative impact of this disease complex on food security and farmer livelihoods is substantial. A key finding to emerge from this comparative treatment is the extent of symptomatic overlap between disease categories. Wilting, leaf spotting, chlorosis, and stunting are common presentations across fungal, bacterial, and viral infections alike, meaning that visual diagnosis in the field, without reference to epidemiological context or laboratory confirmation, carries a real risk of misidentification and, consequently, mismanagement. This chapter's side-by-side framework — organising each disease by causal agent, symptomatology, epidemiology, and

management response — is intended to reduce that risk by equipping readers with a structured basis for differential diagnosis.

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